The Astronomical Journal, 148:119 (11pp), 2014 December doi:10.1088/0004-6256/148/6/119

UCAC4 NEARBY STAR SURVEY: A SEARCH FOR OUR STELLAR NEIGHBORS

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Received 2014 May 22; accepted 2014 August 12; published 2014 November 4

ABSTRACT

We use data from the U.S. Naval Observatory fourth CCD Astrograph Catalog (UCAC4) in combination with photometry from the AAVSO Photometric All-Sky Survey and Two Micron All-Sky Survey to identify stars within 25 pc of the Sun. A sample of nearby stars with accurate trigonometric parallaxes from the Research Consortium On Nearby Stars is used to generate a set of 16 new photometric color–M_{K_s} relations that provide distance estimates with uncertainties of 15%. This work expands the available suites of well-calibrated photometric distance relations that can be used to identify nearby stellar systems. The distance relations are used with quality cuts to extract an initial sample of stars from the UCAC4 estimated to be within 25 pc. Color, proper motion, and existing literature sources are then used to obtain a clean sample of red dwarfs, while limiting the amount of contamination from background giants, resulting in a sample of 1761 candidate nearby stars within 25 pc. Of these, 339 are new discoveries with no previously known published parallax or distance estimate, primarily with proper motions less than 0.2 arcsec yr^{-1}. Five stars are estimated to be within 10 pc, with the nearest, TYC 3980 1081 1, with $V = 10.50$ estimated to be at 5.9 pc. That several hundred new stars have been revealed so close to the Sun illustrates once again that there is considerable work yet to be done to map the solar neighborhood and that additional nearby stars are likely still to be discovered.

Key words: astrometry – solar neighborhood – stars: distances – stars: statistics – surveys – techniques: photometric

Online-only material: machine-readable and VO tables

1. INTRODUCTION

A comprehensive census of the nearby stars is required to determine accurate stellar luminosity and mass functions in the solar neighborhood, and is vital to our understanding of the distribution of stellar mass among different types of stars throughout the Galaxy. In addition, because of their proximity to the Sun, the nearest stars are the most accessible for surveys of stellar activity, ages, multiplicity, and exoplanets. A volume-limited sample of stars is dominated by red dwarfs that make up more than 70% of stellar objects in our Galaxy (Henry et al. 2006). Still, red dwarfs are currently under-sampled by volume because of their low luminosities, coupled with the magnitude limits of current all-sky surveys and the astrometric limitations of scanned plates. Ground-based surveys like the U.S. Naval Observatory Robotic Astrometric Telescope (URAT) (Zacharias 2005) currently underway (Finch et al. 2012a, 2014) will pick up stars down to 18th magnitude, while space missions like *Gaia* (launched in 2013 December) will reach to 20th magnitude.

Significant discoveries of nearby stars have been made in the past decade by searching the Digitized Sky Survey in the northern sky (Lépine 2005, 2008), the SuperCOSMOS Sky Survey in the southern sky (Hambly et al. 2004; Henry et al. 2004; Subasavage et al. 2005a, 2005b; Finch et al. 2007; Boyd et al. 2011a, 2011b; Scholz et al. 2000, 2002), and the USNO CCD Astrograph Catalog (UCAC), also in the southern sky (Finch et al. 2010, 2012b). All of these studies rely primarily on searching for stellar systems with detectable proper motions. Nonetheless, currently available data sets have yet to be completely searched for nearby stars, particularly those with small proper motions.

In this paper we search the more than 100 million sources in the U.S. Naval Observatory fourth CCD Astrograph Catalog (UCAC4; Zacharias et al. 2013), which reaches to 16th magnitude, to reveal nearby stars. This all-sky survey takes advantage of the newly released astrometric results from the UCAC4 along with merged optical photometry from the American Association of Variable Star Observers (AAVSO) Photometric All Sky Survey (APASS) and infrared photometry from the Two Micron All-Sky Survey (2MASS). With the addition of the APASS photometry in the UCAC4 release, we are now able to create a suite of photometric color–M_{K_s} relations that provide distance estimates to nearby red stars with uncertainties of 15%. Using this suite of relations, we have combed the UCAC4 catalog for candidate nearby stars to reveal new candidates that were missed in previous searches, most of which required that the stars have detectable proper motions. In Section 2 we describe the data sets and creation of the photometric color–M_{K_s} relations that incorporate $BVgriJHK_s$ photometry and high-quality trigonometric parallaxes. We outline the search for nearby star candidates in UCAC4 in Section 3, describe the results in Section 4, and provide concluding remarks in Section 5.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **DEC 2014**	2. REPORT TYPE	3. DATES COVERED **00-00-2014 to 00-00-2014**

4. TITLE AND SUBTITLE **UCAC4 Nearby Star Surey: A Search For our Stellar Neighbors**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Naval Observatory,,Washington,,DC,20392**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

The Astronomical Journal, 148:119 (11pp), 2014 December

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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**12**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

2. DATA AND TECHNIQUES

2.1. UCAC4 and Wide-field Infrared Survey Explorer (ALLWISE)

The UCAC4 catalog, released in 2012 August, is the fourth and final version of the UCAC project. The UCAC4 is an updated version of the UCAC3 (Zacharias et al. 2010) that brings the positional system closer to that of UCAC2 (Zacharias et al. 2004) after a final investigation of the magnitude equation corrections. UCAC4 also has many bug fixes and utilizes the Lick Northern Proper Motion data in place of the previously used Schmidt plate data in the north, resulting in reduced systematic errors in proper motions north of about $-20°$ declination. UCAC4 contains more than 113 million entries, of which nearly 51 million have APASS *BVgri* photometry and nearly 110 million have 2MASS JHK_s. We used a 3 arcsecond match radius in the development of the UCAC4 catalog for inclusion of the 2MASS and APASS supplemental photometric data. Further details can be found in (Zacharias et al. 2013). Fewer sources have APASS photometry at present because of the ongoing progress of the APASS project, which at the time of the UCAC4 release was currently on Data Release 6 (DR6). As of the writing of this manuscript, APASS is at Data Release 7 (DR7).

Included as a supplement for completeness to the photometry we provide ALLWISE photometry in the 3.4, 4.6, 12, and 22 μm mid-infrared bandpasses, hereafter W1, W2, W3, and W4.

2.2. Photometric Distances

To obtain photometric distances for UCAC4 sources, we generated a new set of 16 photometric color–M_{K_s} relations using (a) *BVgri* optical photometry from APASS, (b) JHK_s near-infrared photometry from 2MASS, (c) nearby red dwarfs with high-quality trigonometric parallaxes (defined as having errors of less than 5 milliarcseconds from the Research Consortium On Nearby Stars (RECONS)[6] group, and (d) a set of M dwarfs with spectral types M6.0–M9.5 V within 25 pc referred to as the supplemental sample in Henry et al. (2004, hereafter TSNX). The method used is similar to that in TSNX, in which the M_{K_s} band is used with $UBVRIJHK_s$ photometry to obtain 12 relations. The M_{K_s} band is selected here to boost the number of very red stars having photometry in the band used for luminosities (e.g., fewer very red stars have V photometry), and to mitigate the problem of interstellar reddening (although minimal within 25 pc). The input sample contains 110 stars from RECONS, a 64 star sample from Riedel et al. (2010, hereafter TSNXXII), and 31 stars from the very red supplemental list, bringing the total sample to 205 stars having accurate trigonometric parallaxes.

We matched the input list of 205 parallax stars with the UCAC4 catalog to obtain proper motions and $BVgriJHK_s$ photometry. We filled in missing photometric data (photometry not found in UCAC4) using the APASS website, VizieR, or Aladin as needed. Aladin was also used to verify stars by eye to eliminate any source misidentifications, of which none were found. All parallaxes were updated with the most recent results from the RECONS database, and APASS photometry was updated using DR7 web access when available. All stars in close multiple systems, known subdwarfs, known white dwarfs, stars without enough photometric data for at least seven relations, stars with photometric errors greater than 0.10 magnitude, and stars brighter than the APASS saturation magnitude limits (defined in Table 1) were removed from the list, leaving a total of 168 stars for the color–M_{K_s} relations. This list was then given a final spot check by eye using Aladin and specific catalogs to verify photometry and parallaxes.

Combinations of eight filter bands provide a total of 28 possible color–M_{K_s} relations. Of these, 16 were deemed to be reliable, in that there was at least a one magnitude range in color using the sample of stars available for a fit, and there was a reasonable correlation with M_{K_s}; an example is shown in Figure 1 for $(V - K_s)$. A second-order fit was used for all relations, with higher orders not showing any meaningful improvements. In Table 2, we give the applicable color range, number of stars used, the fit coefficients and the root mean square (rms) values for each of the 16 color relations used in this paper. Some stars do not have the complete set of eight-band photometry available or might lie outside of the applicable color range; thus, the number of stars used for each fit is less than the sample of 168 stars. The equations used for the relations have the following format, shown here for the

Table 1
APASS Photometric Saturation Magnitude Limits[a]

Bandpass	Saturation Limit
B	10.25
V	10.25
g	11.00
r	10.00
i	9.00

[a] As of Data Release Six (DR6).

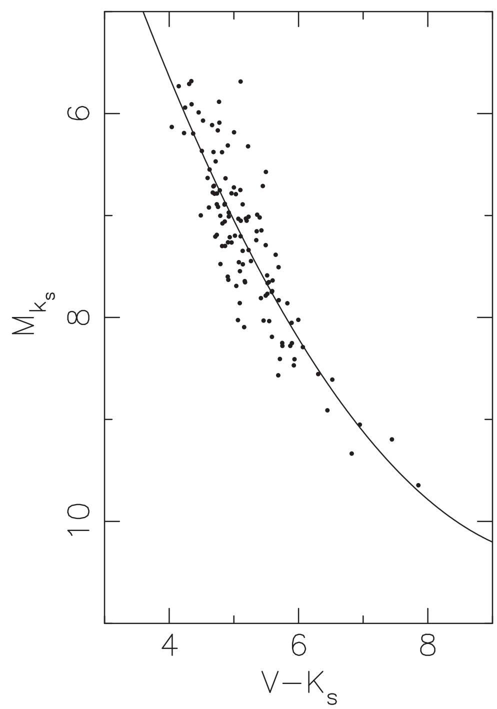

Figure 1. Example color–M_{K_s} fit for the $(V - K_s)$ color relation.

[6] http://www.recons.org

Table 2
Details of the 16 Photometric Distance Relations

Color	Color Range (mag)	Stars Used (number)	Coeff. 1 (× color^2)	Coeff. 2 (× color)	Coeff. 3 (constant)	rms (mag)
V–i	1.4–3.9	113	−0.33800	+3.663	+0.9571	0.38
V–J	3.1–7.0	118	−0.14260	+2.551	−1.0870	0.40
V–H	3.5–7.7	118	−0.13910	+2.657	−2.3950	0.41
V–K	4.0–8.0	118	−0.12390	+2.523	−2.4720	0.42
B–i	2.8–6.0	102	−0.13570	+3.091	−1.6910	0.38
B–J	4.2–9.0	140	−0.08928	+2.188	−2.6330	0.37
B–H	4.9–10.0	141	−0.09372	+2.347	−4.0930	0.39
B–K	5.0–10.0	141	−0.08031	+2.174	−3.8580	0.39
g–i	2.2–4.5	105	−0.13340	+3.619	−1.0110	0.39
g–J	3.9–7.8	113	−0.13290	+2.693	−2.8800	0.39
g–H	4.2–8.4	113	−0.11760	+2.796	−4.2560	0.41
g–K	4.5–8.8	108	−0.13480	+2.637	−4.2120	0.41
r–i	1.0–3.0	105	−0.26210	+3.237	+2.9860	0.41
r–J	2.9–6.2	107	−0.11530	+2.383	+0.2988	0.41
r–H	3.4–6.8	107	−0.28630	+2.502	−0.9758	0.42
r–K	3.5–7.1	102	−0.19210	+2.353	−1.0590	0.42

$(V - K_s)$ relation:

$$M_{K_s} = -0.1239(V - K_s)^2 + 2.523(V - K_s) - 2.472. \quad (1)$$

These relations are similar to those in TSNX in the number of stars used (∼100–140) and rms values (∼0.4 mag). Both suites of relations would benefit by increasing the number of very red stars to extend the applicable ranges of each fit, such as those reported in (Dieterich et al. 2014).

The accuracy of the distance estimates has been evaluated by running the sample of 168 stars used to construct the fits back through the final relations. The resulting average distance errors of the 16 estimates, i.e., the differences between the photometric distance estimates and the distances from the trigonometric parallaxes, is 15.5%. This is virtually identical to the results of TSNX, in which the average error for the 12 relations was found to be 15.3%. We show a comparison of the photometric distance estimates and the trigonometric distances in Figure 2. Of the 168 stars used to construct the relations, 101 (60.1%) lie within the adopted error of 15.5% and 149 (88.7%) lie within two times the adopted error of 15.5%. All distance estimate errors reported in this paper include the 15.5% external error from the fits and the standard deviation from the up to 16 distance estimates for a given star, added in quadrature.

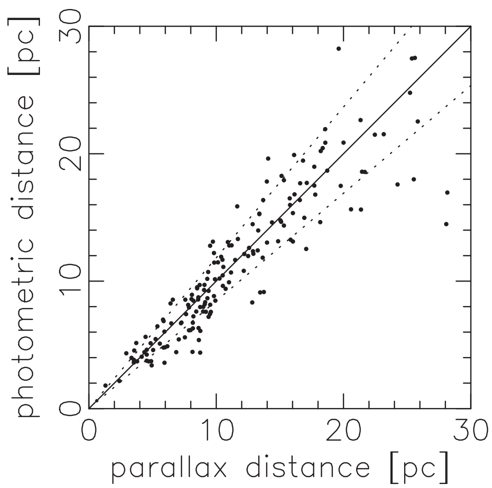

Figure 2. Comparison of the photometric distance estimates and trigonometric distances for the 168 stars used in the creation of the new suite of relations. The solid line indicates perfect agreement, while the dotted lines represent the average 15.5% error.

3. SEARCH FOR NEARBY STARS IN UCAC4

We used a series of four cuts of the UCAC4+APASS +2MASS databases to extract a candidate list of stars within 25 pc. In the first cut, sources were extracted from UCAC4 that met the following criteria.

1. Target must have photometry in at least two filters in the APASS catalog, with photometry errors (apase) $\lesssim$0.10 mag.
2. Target must have photometry in all three JHK_s filters in the 2MASS catalog, with photometry errors (e2mpho) $\lesssim$0.10 mag.
3. Target must not have a UCAC object flag (objt) = 1 or 2, indicating it is near an overexposed star or a streaked object.
4. Target must have a valid, non-zero proper motion in UCAC4.
5. Target must have a Lyon–Meudon Extragalactic DAtabase (LEDA) galaxy flag (leda) = 0 and a 2MASS extended source flag (2mx) = 0—both indicate a point source.

There were 25,865,591 sources output from this query. Those were then run through the suite of photometric distance relations and a second cut was performed that extracted only those for which (a) at least 7 of the 16 relations could be applied, and (b) distances were estimated to be within 25 pc, yielding a list of 381,054 candidate nearby stars.

To build a data set for further investigation, this list was then cross-matched using a 30 arcsecond radius with the RECONS 25 Parsec Database, the *Hipparcos* catalog via VizieR, SIMBAD, and selected journal papers to gather names, spectral types, parallaxes, distance estimates, and other useful information about these stars. During this process, we noticed that many candidates were either associated with or within 30 arcseconds of X-ray sources; these candidates are noted as such in the tables. A list of journal publications and online

Table 3
List of Journal Publications and Online Catalogs Used While Searching for Information on Stars in the Candidate Nearby Star List

Description	Reference
A Catalog of Northern Stars with Annual Proper Motions Larger than 0."15	(Lépine & Shara 2005)
An All-sky Catalog of Bright M Dwarfs	(Lépine & Gaidos 2011)
Carbon-enhanced metal-poor stars	(Masseron et al. 2010)
Carbon-rich giants in the HR diagram	(Bergeat et al. 2002)
Carbon stars from the Hamburg/ESO survey	(Christlieb et al. 2001)
Characterization of M, L, and T Dwarfs in the Sloan Digital Sky Survey	(Hawley et al. 2002)
Contributions to the Nearby Stars (NStars) Project: The Northern Sample. I.	(Gray et al. 2003)
Contributions to the Nearby Stars (NStars) Project: The Southern Sample	(Gray et al. 2006)
Galactic mass-losing AGB stars probed with the IRTS. I.	(le Bertre et al. 2001)
Galactic mass-losing AGB stars probed with the IRTS. II.	(le Bertre et al. 2003)
Hiding in Plain Sight	(Riedel 2012)
Identification of New M Dwarfs in the Solar Neighborhood	(Riaz et al. 2006)
Luminous Carbon stars in Galactic Plane	(Kastner et al. 1993)
Meeting the Cool Neighbors. VII.	(Reid et al. 2003)
Meeting the Cool Neighbors. VIII.	(Reid et al. 2004)
Nearby Stars from the LSPM-North Proper-Motion Catalog. I.	(Lépine 2005)
Near-infrared photometry of carbon stars	(Whitelock et al. 2006)
New High Proper Motion Stars from the Digitized Sky Survey. III.	(Lépine 2005)
Palomar/MSU nearby star spectroscopic survey	(Reid et al. 1995)
Southern infrared proper motion survey. I.	(Deacon et al. 2005)
Southern infrared proper motion survey. II.	(Deacon & Hambly 2007)
Spectroscopic Survey of M Dwarfs within 100 Parsecs of the Sun	(Bochanski et al. 2005)
The HIPPARCOS and Tycho catalogs	(ESA 1997)
The Palomar/MSU Nearby Star Spectroscopic Survey. III.	(Gizis et al. 2002)
The Solar Neighborhood. VIII.	(Hambly et al. 2004)
The Solar Neighborhood. X.	(Henry et al. 2004)
The Solar Neighborhood. XII.	(Subasavage et al. 2005a)
The Solar Neighborhood. XV.	(Subasavage et al. 2005b)
The Solar Neighborhood. XVIII.	(Finch et al. 2007)
The Solar Neighborhood. XXV.	(Boyd et al. 2011b)
The Solar Neighborhood. XXVII.	(Boyd et al. 2011a)
The Tycho-2 catalog	(Hoeg et al. 2000)
Trigonometric Parallaxes for 1507 Nearby Mid-to Late M-dwarfs	(Dittmann et al. 2014)

catalogs used during this search to help build the data set is given in Table 3.

Removing background giants from this large candidate nearby star sample was accomplished using two more cuts. The third cut identifies giants using $J-K_s$ and $V-K_s$ colors, similar to the techniques outlined in Riedel (2012) for candidates extracted using SuperCOSMOS and 2MASS data. The fourth cut uses the UCAC4 proper motions in a Reduced Proper Motion diagram (RPM), as seen in Lépine & Gaidos (2011) and similar to the RPM diagrams in Subasavage et al. (2005a, 2005b), Finch et al. (2007), and Boyd et al. (2011a, 2011b) to further eliminate any contamination.

In the top panel of Figure 3 we show a sample of known giants (dots) and M dwarfs (open circles) pulled from the 381,054 candidate nearby star list, supplemented with a known sample of dwarfs from RECONS. Using $V-K_s$ and $J-K_s$ colors, we constructed two boxes similar to those in Riedel (2012) that likely contain M dwarfs (vertices are given in Table 4). Box 1 contains the most likely M dwarf candidates, while box 2 is more likely to be contaminated by giants. The bottom panel in Figure 3 shows the entire 381,054 sample of nearby star candidates, and after the third cut, we reduce the sample to 4424 candidates that are found in the two boxes.

To further eliminate background giants, the fourth cut utilizes proper motions from UCAC4, combined with photometry from APASS and 2MASS, to plot an RPM diagram. We used a modified distance modulus Equation, where μ in arcsec yr^{-1} is substituted for distance:

$$H_v = V + 5\log\mu + 5. \qquad (2)$$

An RPM diagram is useful in separating dwarfs and giants because distant giants tend to have very slow proper motions compared to nearby dwarfs. In the top plot of Figure 4, we show an RPM diagram of the same known sample of giants (dots) and M dwarfs (open circles) used in Figure 3. A delimiting line is drawn to separate the two classes of stars, with vertices at (2, 8) and (8.5, 16). In the bottom plot of Figure 4, we show the entire initial sample of 381,054 candidates, and use the RPM cut to eliminate another 2408 presumed giants from the 4424 candidates in the two boxes outlined in Figure 3 for the color cut, yielding 2016 candidate nearby stars. After removing 255 duplicate entries, which we found to be the only duplicates in the entire initial 381,054 sample, we are left with a manageable list of 1761 candidate nearby stars.

After the color and RPM cuts, all stars having known parallaxes (669), distance estimates in a published paper (749), or known to be giants (4) were extracted, leaving 339 new candidate nearby stars within 25 pc. Details for all 1761 nearby candidates are given in Tables 5 (339 new discoveries) and 6 (1422 recovered stars), where we give the system names, R.A. and decl. coordinates, proper motions in R.A. and decl. with associated errors, $BVgriJHK_sW1W2W3W4$ photometry, distance estimates with associated errors, the number of color relations used for the estimates (typically all 16) and relevant notes. In Table 6, we provide additional columns for published distances and the type of distance (P = photometric distance; T = trigonometric distance). The first 28 lines of Table 5 are provided in the printed journal sorted by distance and representing all new candidate nearby star systems out to 15 pc. The first 15 lines of Table 6 are provided in the printed journal sorted by RA. The full versions of Tables 5 and 6 can be found in the electronic version of this paper. All positions, proper motions, and $BVgriJHK_s$ come directly from the UCAC4 with some APASS photometry updated to the recent DR7 release for those stars with missing photometry (current release data can be found at www.aavso.org/apass). If no photometry was found or the photometry between 2MASS and APASS was not in agreement in the UCAC4 then the APASS and 2MASS databases were searched manually using either VizeiR or the APASS websites to check for consistency and to fill in gaps.

As a final check, the 339 new nearby candidates were evaluated by eye using Aladin to reveal false detections and to verify proper motions. Of these, 101 did not show any detectable proper motion (noted in Table 5). Further

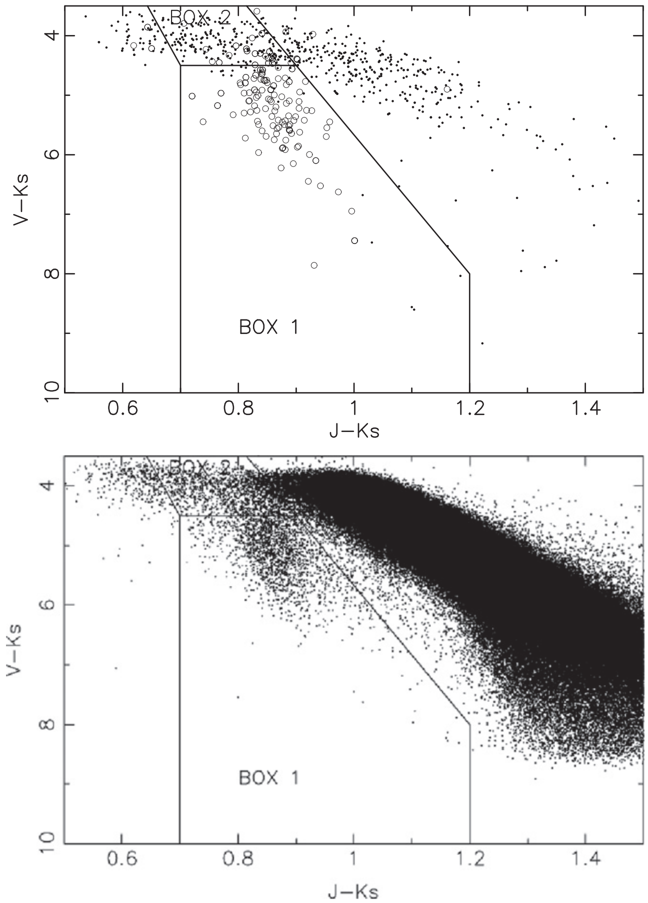

Figure 3. $V - K_s$ vs. $J - K_s$ color–color plots showing (top) a sample of known giants (dots) and M dwarfs (open circles) from the 381,054 candidate nearby star sample, including a supplement sample from RECONS to help construct BOX 1 and BOX 2, and (bottom) the entire 381,054 stars from the candidate nearby star sample.

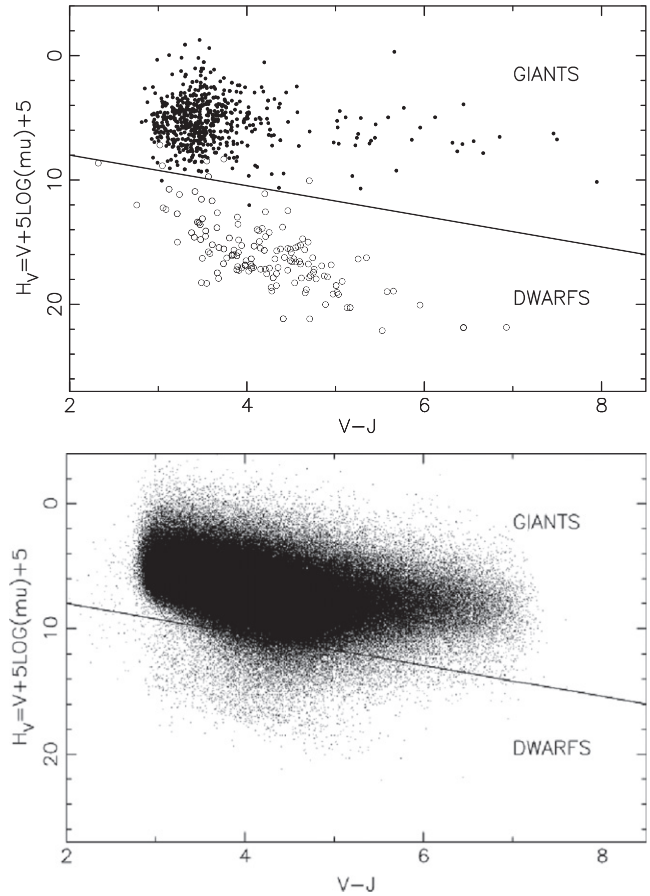

Figure 4. Reduced proper motion diagram showing (top) a sample of known giants (dots) and M dwarfs (open circles) from the 381,054 candidate nearby star sample, supplemented with a sample of stars from RECONS having known parallaxes to help construct a delimiting line, and (bottom) the 381,054 stars from the candidate nearby star sample.

Table 4
Verticies of Box1 and Box2 Chosen From Figure 3

	J–K_s	V–K_s
box 1	0.70	4.5
	0.90	4.5
	1.20	8.0
	1.20	10.0
	0.70	10.0
box 2	0.70	4.5
	0.90	4.5
	0.81	3.5
	0.64	3.5

investigation showed that all but six of the 101 objects had fewer than one arcsecond of total UCAC4 proper motion given the epoch spread of the digitized plates used for visual inspection.

Finally, it is evident from looking at Figures 3 and 4 that a few bona fide M dwarfs are seen outside the boxes or above the delimiting line. As a result of the cuts, eight known M dwarfs were omitted from a sample of 181 known M dwarfs, the same sample shown in the top panels of Figures 3 and 4, which indicates that we have omitted ~4% of nearby stars by our search method. Ultimately, given that our goal is a clean sample of dwarfs, we have omitted a few in favor of minimizing contamination by giants.

4. RESULTS

The 339 new nearby star candidates are all estimated to be within 25 pc of the Sun, including 5 predicted to be within 10 pc. Of the new 339 nearby star candidates, 218 are previously unknown proper motion stars and have been given a USNO Proper Motion (UPM) name designation for this paper, consistent with previous discoveries from our UCAC efforts (Finch et al. 2010, 2012b).

In Figure 5, we show a color–magnitude plot of 479 known stars with trigonometric parallaxes in Table 6 having available ALLWISE photometry (top) and the same color–magnitude plot of the 339 new nearby star candidates from Table 5 (bottom) for comparison. In Figure 6, we show a color–color plot of 479 known stars with trigonometric parallaxes in Table 6 having available ALLWISE photometry (top) and the same color–color plot of the 339 new nearby star candidates from Table 5 (bottom) for comparison. The known sample (top) in Figures 5 and 6 show some outliers from the bulk of the sample which have been labeled on the plot. The new nearby star candidates reported in this paper compare well with the bulk of the known sample.

Table 5
Photometric Distance Estimates for New Candidate Nearby Star Systems

Name	R.A. (deg)	Decl. (deg)	PMRA (mas yr^{-1})	Error (mas yr^{-1})	PMDC (mas yr^{-1})	Error (mas yr^{-1})	B (mag)	V (mag)	g (mag)	r (mag)	i (mag)	J (mag)	H (mag)	K_s (mag)	$W1$ (mag)	$W2$ (mag)	$W3$ (mag)	$W4$ (mag)	Dist. est. (pc)	Error (pc)	Colors #	Notes
TYC 3980-1081-1	327.9096831	59.2941733	−79.9	0.8	69.1	0.8	11.958	10.501	11.185	9.980	8.600	6.529	5.860	5.651	5.320	5.150	5.254	5.140	5.93	1.32	16	a,b,d
L 173-19	30.1595833	−55.9679703	118.5	1.5	−69.1	1.1	13.467	11.877	12.617	11.270	9.809	7.625	7.088	6.773	6.619	6.382	6.362	6.176	8.47	1.50	16	a
2MASS J20490993-4012062	312.2914328	−40.2017892	−51.4	1.5	1.7	1.5	15.294	13.532	14.278	12.825	10.994	8.596	8.018	7.704	7.474	7.295	7.163	7.123	8.66	1.48	16	a,b
BPS CS 22898-0066	317.5192247	−19.3417936	87.0	1.4	−94.4	3.1	14.673	13.143	13.872	12.546	10.880	8.428	7.883	7.552	7.305	7.161	7.067	6.768	9.58	2.18	16	a,b
TYC 3251-1875-1	3.9126392	47.5894489	−83.0	1.2	−20.7	1.2	12.605	11.120	11.804	10.511	9.234	7.336	6.709	6.467	6.349	6.107	6.132	6.003	9.66	1.81	16	a,b
UPM 0815-2344	123.7966400	−23.7376783	102.4	2.3	66.4	2.4	13.654	12.304	12.941	11.696	10.237	8.107	7.513	7.215	6.983	6.892	6.774	6.683	11.11	2.60	16	a
2MASS J11473762 + 0501106	176.9067664	5.0196183	51.8	2.5	19.6	3.7	13.927	12.383	13.090	11.769	10.361	8.223	7.644	7.381	7.155	7.062	6.965	6.852	11.92	2.17	16	a,b,d
UPM 1012-3124	153.0378781	−31.4125789	−74.8	1.1	−9.4	1.0	15.052	13.460	14.165	12.879	11.189	8.848	8.262	7.993	7.758	7.497	6.128	4.798	12.08	2.41	16	a
UPM 1951-3100	297.9184097	−31.0060642	33.9	2.0	−148.0	0.9	13.929	12.307	13.056	11.654	10.148	8.251	7.698	7.409	7.224	7.069	6.975	6.845	12.18	2.76	16	a
V* V549 Hya	173.1715497	−26.8692036	−95.3	2.2	−28.6	4.7	17.235	15.647	16.425	14.800	13.080	9.837	9.276	9.012	8.928	8.645	8.481	8.536	12.36	4.37	16	a,b
SCR 0757-7114	119.3855169	−71.2482950	86.7	1.3	20.6	1.3	13.926	12.394	13.082	11.833	10.340	8.319	7.745	7.423	7.172	7.127	7.038	6.910	12.39	2.44	16	a,d
EM* StHA 10	28.2390044	8.5574914	96.0	4.4	15.5	4.5	15.641	14.055	14.754	13.448	11.575	9.238	8.638	8.358	8.216	8.009	7.864	7.739	12.57	2.52	16	a,b,d
LHS 1918	112.0545703	−18.7932367	−11.5	8.0	613.7	8.0	15.365	13.668	14.411	13.035	11.322	9.049	8.454	8.167	7.995	7.785	7.657	7.385	12.61	2.06	16	a
PPMX 010320.9-134823	15.8373589	−13.8064025	76.5	6.1	43.9	6.0	13.544	12.026	12.748	11.441	10.152	8.138	7.571	7.258	7.032	7.002	6.929	6.791	13.15	2.37	16	a
LTT 5790	219.4733411	−34.6547450	−216.4	8.0	−103.7	8.0	14.423	12.920	13.593	12.335	10.835	8.674	8.003	7.762	7.611	7.485	7.366	7.138	13.26	2.79	16	a
2MASS J01283952-1458042	22.1647592	−14.9679017	−17.1	3.8	−30.7	5.0	15.346	13.645	14.441	12.991	11.360	9.058	8.555	8.198	8.013	7.819	7.693	7.652	13.28	2.38	16	a,b
UPM 1845-2855	281.4895431	−28.9314258	−59.4	5.3	−93.1	20.2	14.067	12.611	13.231	12.044	10.538	8.414	7.897	7.603	7.410	7.265	7.190	7.030	13.29	2.87	16	a
TYC 4823-2265-1	108.2967531	−5.1968422	−19.1	3.7	−304.7	4.8	12.730	11.183	11.955	10.533	9.496	7.649	7.077	6.819	6.707	6.478	6.464	6.320	13.44	2.52	15	b,c,d
UPM 1816-5844	274.0515567	−58.7348769	−4.2	2.2	−139.5	2.2	14.268	12.743	13.471	12.127	10.687	8.599	7.964	7.699	7.576	7.417	7.299	7.069	13.55	2.54	16	a,b
UPM 0402-0242B	60.6350025	−2.7093081	34.8	3.2	−38.2	2.0	14.022	12.458	13.180	11.885	10.516	8.451	7.830	7.552	7.387	7.240	7.167	7.006	13.72	2.52	16	a,d
UPM 2303-4650	345.8983450	−46.8464178	−171.6	1.1	−20.1	1.1	15.545	13.848	14.591	13.241	11.534	9.217	8.686	8.360	8.192	7.984	7.846	7.724	13.92	2.35	16	a
G 162-70	158.7546747	−9.4107175	222.7	8.7	−179.8	10.5	13.677	12.153	12.869	11.574	10.265	8.276	7.678	7.393	7.140	7.118	7.039	6.865	13.93	2.49	16	a
UPM 1709-5957	257.4430214	−59.9604250	−43.2	2.2	−60.0	2.2	14.975	13.411	14.069	12.790	11.131	9.003	8.388	8.127	7.943	7.759	7.629	7.507	14.13	2.77	16	a,b

Table 5
(Continued)

Name	R.A. (deg)	Decl. (deg)	PMRA (mas yr^{-1})	Error (mas yr^{-1})	PMDC (mas yr^{-1})	Error (mas yr^{-1})	B (mag)	V (mag)	g (mag)	r (mag)	i (mag)	J (mag)	H (mag)	K_s (mag)	$W1$ (mag)	$W2$ (mag)	$W3$ (mag)	$W4$ (mag)	Dist. est. (pc)	Error (pc)	Colors #	Notes
UPM 0838-2843	129.6405922	−28.7239958	79.2	1.5	−129.2	1.5	13.508	11.864	12.642	11.239	10.031	8.108	7.584	7.282	7.000	6.931	6.854	6.704	14.22	2.75	16	[a]
UPM 0409-4435	62.3847642	−44.5943072	−20.9	1.3	113.2	1.3	15.923	14.250	14.993	13.647	11.946	9.464	8.912	8.561	8.381	8.191	8.032	7.915	14.31	3.00	16	[a]
2MASS J06134717-2354250	93.4465839	−23.9069047	−33.9	2.4	109.1	1.0	14.521	12.952	13.679	12.359	10.926	8.723	8.160	7.872	7.693	7.538	7.437	7.386	14.34	2.74	16	[a]
UPM 0415-4602	63.9545317	−46.0399694	−93.3	5.3	−86.9	1.7	13.400	11.847	12.591	11.271	9.998	8.120	7.542	7.293	7.074	6.988	6.896	6.766	14.46	2.69	16	[a]
LP 489-3	277.3510525	−34.9625439	−52.4	8.0	−236.0	8.0	13.353	11.877	12.578	11.286	9.997	8.086	7.565	7.327	7.146	6.978	6.930	6.846	14.75	2.93	16	[a]

[a] Candidate selected from box 1, using Figure 3.
[b] Candidate within 30 arcseconds of an X-ray source.
[c] Candidate selected from box 2, using Figure 3.
[d] Candidate's motion could not be verified by eye.

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal. A portion is shown here for guidance regarding its form and content.)

Table 6
Photometric Distance Estimates for Systems Recovered in the Nearby Star Search

Name	R.A. (deg)	Decl. (deg)	PMRA (mas yr^{-1})	Error (mas yr^{-1})	PMDC (mas yr^{-1})	Error (mas yr^{-1})	B (mag)	V (mag)	g (mag)	r (mag)	i (mag)	J (mag)	H (mag)	K_s (mag)	$W1$ (mag)	$W2$ (mag)	$W3$ (mag)	$W4$ (mag)	Dist.est. (pc)	Error (pc)	Colors #	Dist.pub (pc)	Dist.type	Notes
PM I00026 + 3821	0.6671503	38.3625119	−76.2	3.9	−25.3	3.6	15.507	13.931	14.671	13.303	11.785	9.707	9.203	8.911	8.568	8.385	8.265	8.506	22.98	4.45	16	22.08	P	[a]
LP 644-34	1.3952731	−6.1186375	177.5	8.0	−64.4	8.0	14.732	13.147	13.923	12.526	11.275	9.255	8.649	8.411	8.219	8.094	7.983	7.856	22.02	3.91	16	26.11	P	[a]
LHS 1019	1.5797275	−65.8403125	195.8	8.0	−552.5	8.0	13.731	12.188	12.917	11.574	10.367	8.479	7.839	7.631	7.416	7.336	7.226	6.995	17.14	3.06	16	16.71	T	[a]
2MASS J00080642 + 4757025	2.0267508	47.9506631	−126.9	4.4	2.5	2.5	14.390	12.779	13.472	12.150	10.640	8.523	8.000	7.677	7.473	7.336	7.221	6.962	12.76	2.26	16	13.85	P	[a,c]
BPM 46052	2.3331467	−21.2448286	138.5	1.2	−101.9	2.6	13.698	12.179	12.935	11.540	10.512	8.763	8.156	7.937	7.751	7.686	7.586	7.532	23.93	4.61	14	26.67	P	[b]
GSC 04018-02763	2.6066942	62.2104169	−27.5	2.0	35.2	2.0	15.394	13.803	14.514	13.221	11.841	9.655	9.092	8.811	8.605	8.464	8.273	7.660	23.25	4.52	16	20.58	P	[a]
BPS CS 30324-0025	2.6793694	−20.6519094	120.3	1.4	−75.5	1.3	14.909	13.392	14.115	12.757	11.467	9.480	8.860	8.614	8.491	8.359	8.251	8.288	24.05	4.25	16	23.81	P	[a,c]
GJ 0011	3.3163239	69.3270800	717.0	2.5	−292.4	2.5	13.363	12.487	13.198	11.827	10.520	8.556	7.984	7.746	7.562	7.411	7.318	7.208	18.33	6.83	16	21.05	T	[a]
HIP 1083	3.3712489	−36.8286303	−213.8	8.0	−335.2	8.0	12.240	10.781	11.530	10.162	9.394	7.803	7.183	6.962	6.832	6.763	6.716	6.644	20.60	3.82	7	27.22	T	[b]
LTT 17095	3.4112875	80.6658033	249.9	0.9	190.8	0.9	12.626	11.104	11.842	10.517	9.519	7.756	7.131	6.904	6.651	6.707	6.660	6.579	15.58	2.78	13	19.59	T	[b,c]
G 242-049	3.9031153	72.2837533	319.0	8.0	185.0	8.0	13.727	12.362	12.933	11.707	10.593	8.837	8.250	7.991	7.859	7.760	7.682	7.626	24.29	5.26	15	19.80	P	[b]
LHS 1049	3.9305203	−67.9932772	611.2	8.0	−152.9	8.0	14.064	12.531	13.286	11.961	10.752	8.804	8.257	8.020	7.824	7.694	7.598	7.564	20.81	3.59	16	20.12	P	[a]
GJ 0012	3.9553561	13.5562761	621.0	8.0	333.0	8.0	14.265	12.600	13.405	11.963	10.698	8.619	8.068	7.807	…	…	…	…	15.87	3.03	16	11.57	T	[a]
LHS 1051	3.9640403	−67.9976672	611.2	8.0	−152.9	8.0	12.375	10.915	11.664	10.562	9.458	7.795	7.211	6.949	6.840	6.747	6.704	6.572	18.18	4.39	12	21.46	P	[b]
2MASS J00155808-1636578	3.9919686	−16.6160100	−110.2	2.2	35.0	2.2	14.875	13.184	13.976	12.547	11.027	8.736	8.191	7.909	7.690	7.546	7.435	7.214	12.66	2.33	16	17.95	T	[a,c,d]

[a] Candidate selected from box 1, using Figure 3.
[b] Candidate selected from box 2, using Figure 3.
[c] Candidate within 30 arcseconds of an X-ray source.
[d] Distance estimate from this survey differs by more than 2 sigma from published parallax or distance estimate.
[e] Candidate is a known giant.

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal. A portion is shown here for guidance regarding its form and content.)

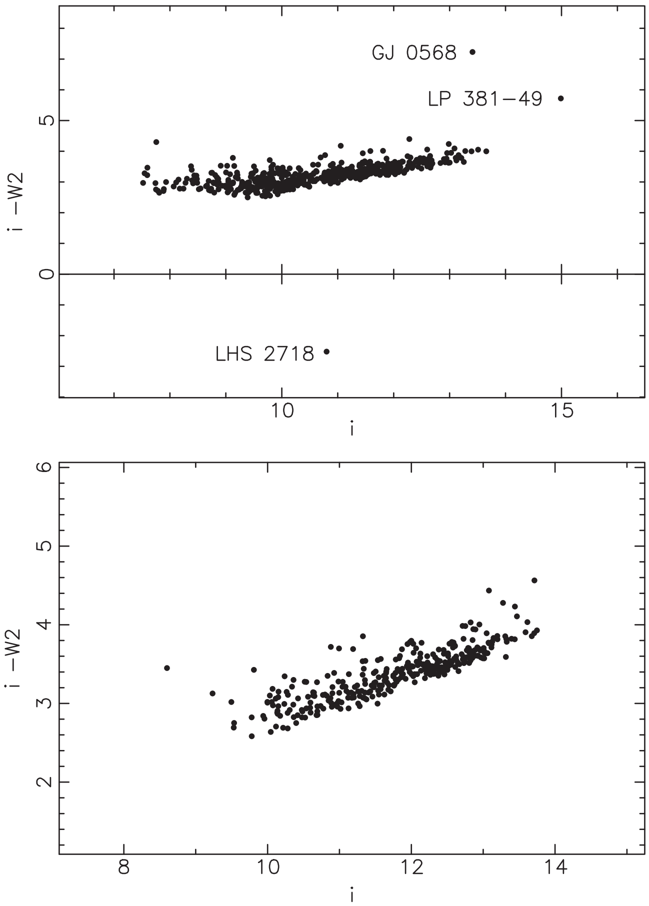

Figure 5. $i-W2$ vs. i color–magnitude plot of 479 known stars from Table 6 having ALLWISE photometry and a trigonometric parallax (top) and the same color–magnitude plot showing the 339 new nearby star candidates from Table 5 (bottom) for comparison.

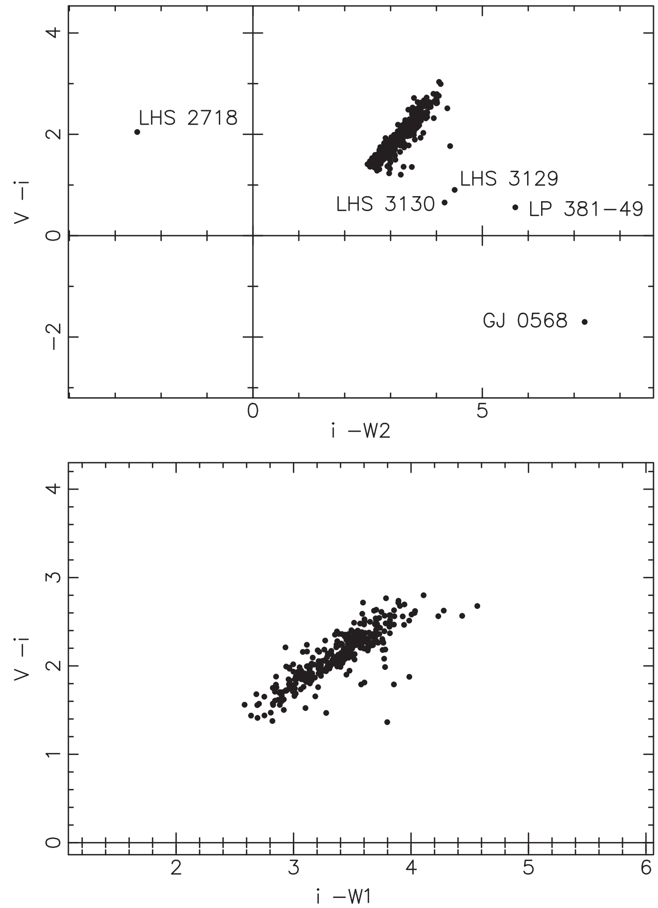

Figure 6. $V-i$ vs. $i-W2$ color–color plot of 479 known stars from Table 6 having ALLWISE photometry and a trigonometric parallax (top) and the same color–color plot showing the 339 new nearby star candidates from Table 5 (bottom) for comparison.

In Figure 7, we show the sky distribution of the 339 new nearby star candidates. This plot shows that during this all-sky survey, more new nearby star candidates were discovered in the southern sky than in the north. This is because the southern hemisphere has historically been less rigorously searched for stars with proper motions less than ∼0$''$18 yr^{-1}, the cutoff of Luyten's all-sky survey (Luyten 1980). In Figure 8, we show a proper motion histogram of the newly discovered nearby star candidates in 0$''$02 yr^{-1} bins, highlighting with dark bars those having distance estimates within 15 pc. This illustrates that most of the new nearby stars we have revealed are found in the slower proper motion regimes, yet each is estimated to be closer than 25 pc.

We used the RECONS 25 pc Database to construct a catalog of 320 stars with accurate trigonometric parallaxes placing them within 10 pc. Many of these objects are very bright (AFGK stars) or very faint (brown dwarfs), and are therefore outside the limits of our current search, which targets red dwarfs. A detailed analysis indicates that 75 did not match up to any UCAC4 entry, 34 did not contain any APASS photometry in UCAC4, 54 did not have any 2MASS photometry listed in UCAC4, 75 did not contain photometry with errors less than or equal to 0.10 mag, 10 did not meet the color range for the relations, 9 did not meet the criteria of using at least 7 relations for the distance estimate, and 1 was rejected because of an object flag. Of the remaining 62 stars that were recovered successfully, 51 (82%) are estimated to be within 10 pc using the relations presented here, and only 1 is estimated to be beyond 15 pc. We conclude that our search is successful in revealing nearby red dwarfs, and that our new relations provide reasonable distance estimates.

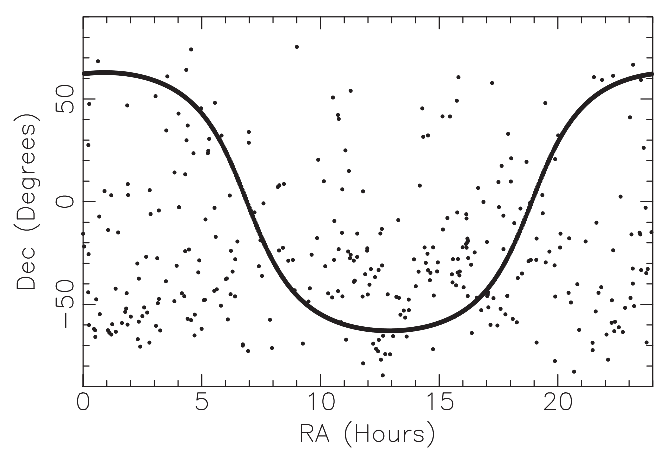

Figure 7. Sky distribution of the 339 new nearby star candidates reported in this paper. The curve represents the Galactic plane.

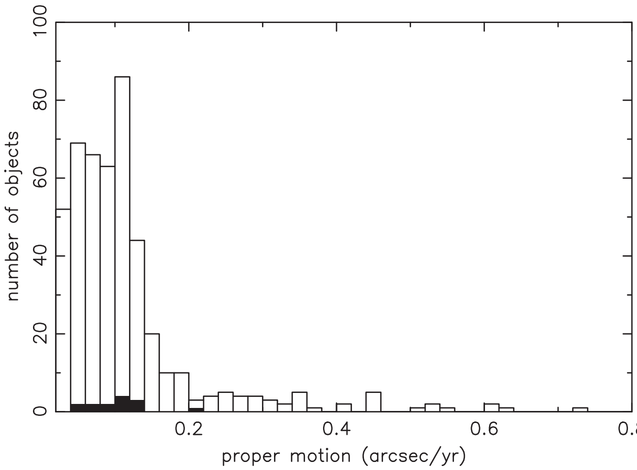

Figure 8. Histogram showing the number of proper motion objects in 0″.02 yr^{-1} bins for all new nearby star candidates (light shade) and the number of those objects having distance estimates within 15 pc (dark shade).

4.1. Local Statistics

As of 2014 January 1, there are 270 systems known to be within 10 pc of the Sun (Henry et al. 2006) and updates on (www.recons.org). This census is extracted from the RECONS 25 pc Database, which includes all systems having trigonometric parallaxes of at least 40 mas and errors of 10 mas or less, reported in the refereed literature. Our survey for nearby stars in the UCAC4 has turned up 13 stars predicted to be within 10 pc that have no published trigonometric parallaxes. Eight of the 13 stars have previously published distance estimates, and here we provide the first distance estimates for the remaining five candidates: TYC 3980-1081-1 (5.9 pc), L 173-19 (8.47 pc), 2MASS J20490993-4012062 (8.66 pc), BPS CS 22898-0066 (9.58 pc), and TYC 3251-1875-1 (9.66 pc).

Seven of the 13 stars are already on the RECONS astrometry program being carried out at the CTIO/SMARTS 0.9 m (Jao et al. 2005). Two have trigonometric parallaxes recently published in (Riedel et al. 2014)—2MASS J07491271-7642065 (L034-026) at 10.6 pc and L 449-001AB at 11.9 pc. Results for the other five indicate that four are indeed within 10 pc (and will soon be published), while the fifth is a young star at 43.2 pc. The remaining six stars are either too far north for the astrometry program in Chile or may be added to determine parallaxes.

Expansion of this core sample of 10 pc stars to those within 25 pc allows us to determine more robust luminosity and mass functions in the solar neighborhood, which provide benchmarks for our understanding of the stellar content of our Galaxy, as well as other galaxies. Although the color and proper motion cuts described above were successful at eliminating many background giants, the remaining sample will still suffer from some contamination. We evaluate the fraction of the 339 new nearby candidates likely to be within 25 pc by examining the 672 having known parallaxes included in the recovered sample Table 6. Of those, 562 have parallaxes placing them within 25 pc, whereas 110 are beyond 25 pc, for a success rate of 84%. This implies that ∼285 of the discoveries are likely to be within 25 pc.

As of 2014 January 1, there are 2168 systems known within 25 pc that have accurate trigonometric parallaxes. The anticipated 285 new systems within 25 pc found in this UCAC4 survey may therefore increase the sample by as much as 13%. Those stars that prove to be further than 25 pc will be overluminous, typically because they are unresolved multiples and/or young stars. Thus, while not every one of the new discoveries first reported here will be a star within 25 pc, even those beyond 25 pc are likely to be astrophysically compelling targets.

5. CONCLUSIONS

We have identified 339 new nearby star candidates within 25 pc via this search, of which 218 were previously unidentified in *any* search or catalog. Most of these new discoveries are nearby stars with proper motions less than 0.2 arcsec yr^{-1}, indicating that many of the Sun's nearest neighbors have been missed to date because of the emphasis on larger proper motions.

The 16 relations reported here can be used to estimate distances to nearby red dwarfs within the applicable color ranges given in Table 2. The relations are quite reliable, as evidenced by the number of nearby stars recovered during the search. The primary limitations of the method are a lack of APASS sky coverage, and that the relations focus on red dwarfs only. This search used the UCAC4 catalog as a starting point, but a new search could be done once the APASS and upcoming URAT catalogs are complete, providing improved photometric sky coverage and depth.

Followup trigonometric parallax measurements are required to confirm which of the nearby star candidates are, in fact, closer than 25 pc. Given continued observations by the RECONS team from the ground, and *Gaia*'*s* anticipated astrometric accuracy and limiting magnitude, most or all of these targets should have accurate parallaxes in the coming years.

We thank the entire UCAC team for making this nearby star search possible. Special thanks go to members of the RECONS team for their support and use of the RECONS 25 pc database. This work has made use of the SIMBAD, VizieR, and Aladin databases operated at the CDS in Strasbourg, France. We have also made use of data from 2MASS, APASS, ALLWISE, and the ADS service.

REFERENCES

Bergeat, J., Knapik, A., & Rutily, B. 2002, A&A, 390, 967
Bochanski, J. J., Hawley, S. L., Reid, I. N., et al. 2005, AJ, 130, 1871
Boyd, M. R., Henry, T. J., Jao, W.-C., Subasavage, J. P., & Hambly, N. C. 2011, AJ, 142, 92
Boyd, M. R., Winters, J. G., Henry, T. J., et al. 2011, AJ, 142, 10
Christlieb, N., Green, P. J., Wisotzki, L., & Reimers, D. 2001, A&A, 375, 366
Deacon, N. R., Hambly, N. C., & Cooke, J. A. 2005, A&A, 435, 363
Deacon, N. R., & Hambly, N. C. 2007, A&A, 468, 163
Dieterich, S. B., Henry, T. J., Jao, W.-C., et al. 2014, AJ, 147, 94
Dittmann, J. A., Irwin, J. M., Charbonneau, D., & Berta-Thompson, Z. K. 2014, arXiv:1312.3241
ESA, 1997, VizieR Online Data Catalog, 1239, 0
Finch, C. T., Bredthauer, G., DiVittorio, M., et al. 2012, AASM, 220, 135.05
Finch, C. T., Henry, T. J., Subasavage, J. P., Jao, W.-C., & Hambly, N. C. 2007, AJ, 133, 2898
Finch, C. T., Zacharias, N., & Henry, T. J. 2010, AJ, 140, 844
Finch, C. T., Zacharias, N., Boyd, M. R., Henry, T. J., & Hambly, N. C. 2012, ApJ, 745, 118
Finch, C. T., Zacharias, N., DiVittorio, M., et al. 2014, AAS/Division of Dynamical Astronomy Meeting, 45, #305.02
Gizis, J. E., Reid, I. N., & Hawley, S. L. 2002, AJ, 123, 3356

Gray, R. O., Corbally, C. J., Garrison, R. F., McFadden, M. T., & Robinson, P. E. 2003, AJ, 126, 2048
Hambly, N. C., Henry, T. J., Subasavage, J. P., Brown, M. A., & Jao, W.-C. 2004, AJ, 128, 437
Hawley, S. L., Covey, K. R., Knapp, G. R., et al. 2002, AJ, 123, 3409
Henry, T. J., Jao, W.-C., Subasavage, J. P., et al. 2006, AJ, 132, 2360
Henry, T. J., Subasavage, J. P., Brown, M. A., et al. 2004, AJ, 128, 2460
Høg, E., Fabricius, C., Makarov, V. V., et al. 2000, A&A, 355, L27
Jao, W.-C., Henry, T. J., Subasavage, J. P., et al. 2005, AJ, 129, 1954
Kastner, J. H., Forveille, T., Zuckerman, B., & Omont, A. 1993, A&A, 275, 163
Le Bertre, T., Matsuura, M., Winters, J. M., et al. 2001, A&A, 376, 997
Le Bertre, T., Tanaka, M., Yamamura, I., & Murakami, H. 2003, A&A, 403, 943
Lépine, S. 2005, AJ, 130, 1680
Lépine, S. 2005, AJ, 130, 1247
Lépine, S. 2008, AJ, 135, 2177
Lépine, S., & Gaidos, E. 2011, AJ, 142, 138
Lépine, S., & Shara, M. M. 2005, AJ, 129, 1483
Luyten, W. J. 1980, Proper Motion Survey with the 48-inch Telescope, 55, (Minneapolis, MN: Univ. Minnesota Press) 1
Masseron, T., Johnson, J. A., Plez, B., et al. 2010, A&A, 509, A93
Reid, I. N., Cruz, K. L., Allen, P., et al. 2003, AJ, 126, 3007
Reid, I. N., Cruz, K. L., Allen, P., et al. 2004, AJ, 128, 463
Reid, I. N., Hawley, S. L., & Gizis, J. E. 1995, AJ, 110, 1838
Riaz, B., Gizis, J. E., & Harvin, J. 2006, AJ, 132, 866
Riedel, A. R. 2012, PhD thesis, Georgia State Univ.
Riedel, A. R., Finch, C. T., Henry, T. J., et al. 2014, AJ, 147, 85
Riedel, A. R., Subasavage, J. P., Finch, C. T., et al. 2010, AJ, 140, 897
Scholz, R.-D., Irwin, M., Ibata, R., H., Jahreiß, & O. Y., Malkov 2000, A&A, 353, 958
Scholz, R.-D., Szokoly, G. P., Andersen, M., Ibata, R., & Irwin, M. J. 2002, ApJ, 565, 539
Subasavage, J. P., Henry, T. J., Hambly, N. C., Brown, M. A., & Jao, W.-C. 2005, AJ, 129, 413
Subasavage, J. P., Henry, T. J., Hambly, N. C., et al. 2005, AJ, 130, 1658
Whitelock, P. A., Feast, M. W., Marang, F., & Groenewegen, M. A. T. 2006, MNRAS, 369, 751
Zacharias, N., Urban, S. E., Zacharias, M. I., et al. 2004, AJ, 127, 3043
Zacharias, N. 2005, Astrometry in the Age of the Next Generation of Large Telescopes, 338, 98
Zacharias, N., Finch, C., Girard, T., et al. 2010, AJ, 139, 2184
Zacharias, N., Finch, C. T., Girard, T. M., et al. 2013, AJ, 145, 44